STRATIGRAPHY AND STRUCTURE OF THE PARK CITY MINING DISTRICT, UTAH[1]

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INTRODUCTION

The Central Wasatch supplied evidence for important principles to the pioneer geologists, and valuable data to succeeding investigators, and now, in the light of recent detailed studies, is proving to be a most fruitful geologic field. It was thus the source for epoch-making writings on orogeny by King and Emmons; for significant observations on the relations of certain igneous masses to sediments by Geikie; for the determination of striking facts of pleistocene geologic history by Gilbert; and for important contributions by other geologists.

The first detailed geologic mapping in this historic region was undertaken in August, 1902, in connection with an investigation of the geology and ore deposits of the Park City Mining District. This was continued through the field season of 1903 and completed in 1904. As a necessary preliminary, broad comparative studies of the geology of the range north and south of the immediate area under survey were made, and standard sections, notably one which was unusually well

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exposed in Big Cottonwood Canyon, were carefully measured and critically studied. Among the results secured is the precise definition of several stratigraphic formations, including one carrying a previously undescribed Permian fauna; also the solution of several faults of large offset which bear significantly upon mining operations.

Three brief progress reports have been published. The complete statement of the results of that investigation will go to press this year in the form of a "Professional Paper" of the United States Geological Survey. It seems desirable, however, that certain results should be made public at once. This paper has therefore been prepared by request for the purpose of introducing the names of certain stratigraphic formations for the use of writers on these formations in adjacent regions, and of rendering the broad, structural results of the work available for use by local operators.

In this connection it is a pleasure to acknowledge the valuable contributions toward these final conclusions. Thus, the investigation has throughout been under the general supervision of Mr. S. F. Emmons, and in the first year was carried on jointly by Dr. J. D. Irving and the writer, and during the remaining two years benefited by the service of Mr. L. H. Woolsey. Dr. T. W. Stanton has identified the fossil collections from the Jurassic and Triassic, and also in 1903 kindly co-operated in the field in the solution of special problems of stratigraphic correlation; while Dr. G. H. Girty has determined the fossil collections from the Carboniferous, numbering over 100 distinct lots, and throughout the investigation has given helpful interpretations of paleontological evidence. The writer began his work in the region in October, 1900, when it was his good fortune to discover material proof that the main Little Cottonwood granite mass is intrusive in quartzite of Cambrian age, and that the Alta granodiorite body is intrusive in limestone of Pennsylvanian age.[1] In addition to the detailed study of the immediate Park City District throughout the period of survey, he has also carried on comparative studies in stratigraphic correlation and general geology in adjoining portions of this range and the Uintas.

[1] S. F. Emmons, "Little Cottonwood Granite Body of the Wasatch Mountains," *American Journal of Science*, Vol. XVI (August, 1903), pp. 139–47. J. M Boutwell, "Progress Report on Park City District, Contributions to Economic Geology 1902," U. S. Geological Survey, *Bulletin, No. 213* (March, 1903), p. 36.

GENERAL GEOGRAPHY

The Wasatch Mountains, in their middle course, lie in the eastern part of Utah. They are a lofty, rugged range trending northerly and southerly between the Great Basin on the west and the mountainous plateau regions on the east. From a ragged serrate divide on sharp, ledgy peaks 10,000 to 11,000 feet high, the western slopes fall off abruptly 5,000 to 6,000 feet by a wall-like front of striking steepness to the desert below; while the eastern slope, in marked contrast, gives way gradually to upland ranges, plateaus, and high-lying meadows. This unsymmetrical range may thus be compared to a mammoth step several thousand feet in height from the Great Basin on the west to the highlands which extend from its upward portion eastward. These western slopes are interrupted by deep, narrow, rock-walled canyons, through which the drainage from the uplands and parks escapes westward to the desert. The portions of the western wall which lie between these canyons show a marked type of dissection which is characterized by ravines that rise from the level of the desert with steep sides and bottoms, and fork symmetrically upstream repeatedly. The topography in both its larger and smaller features, showing rugged, precipitous slopes, deep, narrow canyons with ungraded bottoms and side cataracts, is indicative of the youth of this range.

GENERAL GEOLOGY

The rocks which form the range are sedimentary, metamorphic, and igneous. The Wasatch sediments, as concisely described by King,[1] are made up of four great divisions, a purely detrital series of Cambrian age, a great limestone extending from Cambrian to the top of the lower Coal Measures, a body of pure siliceous detritus of upper Carboniferous age, and a fourth body of limestone of upper Coal Measure age. The metamorphic rocks include the early regionally metamorphosed sediments and the locally altered or contact metamorphosed rocks. Beyond the fact that these great metamorphic series are pre-Cambrian, their age is unproved, though they are known to be the oldest rocks in the Wasatch. The igneous rocks include several large granitic and porphyritic intrusives and extensive flows.

[1] Clarence King, *Geological Exploration of the Fortieth Parallel Survey*, Vol. I, pp. 100, 101.

The ages and relationships of some of these masses have not yet been completely established.

Structurally the Wasatch Range is a composite, orographic unit. In the largest conception, it is a linear north-south anticlinal range, truncated on the west and probably south by great faults. This major structure is made up of four parts: (1) the Logan syncline, pitching north; (2) the eastern limb of an anticline, constituting the western rim of a Tertiary basin; (3) in the middle part (*a*) a narrow easterly-westerly syncline and (*b*) an easterly-westerly anticlinal dome; (4) to the south the eastern limb of a north-south syncline, probably truncated south of Mount Nebo by a great northeast-southwest fault, with the downthrow on the southeast. These larger structures are exceedingly complicated by several systems of intricate faulting.

The greatest geological activity in the Wasatch Range was in the middle portion at its junction with the great east-west Uinta Range. Extensive and irregular intrusion, widespread extrusion, thorough contact metamorphism, persistent and recurrent faulting, and glaciation have produced in a comparatively small area highly varied and complex geology. At the heart of the area in the focus of these combined factors have been formed the most extensive and richest ore bodies in the range.

This limited area, about 24 square miles, is known as the Park City District. It lies about 38 miles southeast from Salt Lake City, and embraces in its southwest corner the main divide of the Wasatch (Clayton Peak, 10,728 feet), and a prominent spur descending eastward 4 to 5 miles to high-lying interior valleys. The spur separates the area into three natural topographic divisions, which accord with the rock and structural divisions—namely, the north and northwestern slopes, the eastern slopes, and the southern. In the northern and northwestern portions the complete sedimentary sequence is present, dipping universally to the northwest at a moderate angle. On the eastern slope the same formations occur (with noteworthy variations), dipping in general easterly, much faulted, and intruded by irregular stocks and dikes, and on the northeast partly buried by an extrusive mass. The southern portion embraces the great laccolithic stock of diorite in Clayton Peak on the southwest; dikes and stocks of andesite porphyry cutting upward into the overlying sedimentary formations;

and a great east-west zone of contact metamorphosed sediments. It is these metamorphosed rocks which thus hardened stand up as the backbone of the region, the divide between north and south drainage, and form the home of all the great bonanza ore bodies of the district.

STRATIGRAPHY

GENERAL DESCRIPTION

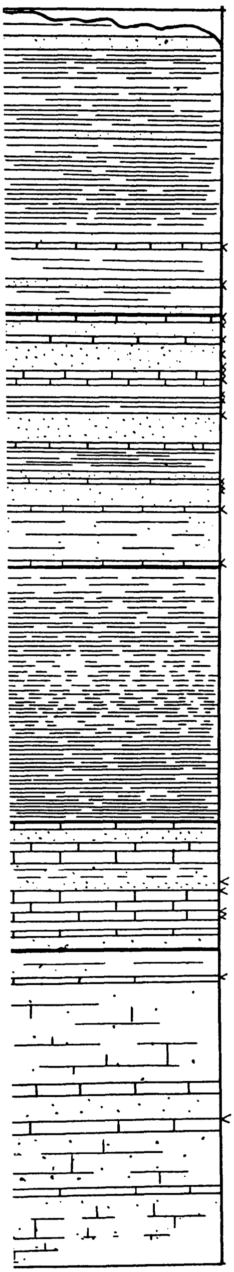
The sedimentary rocks within this district are of Carboniferous and Triassic ages. They are divisible on paleontologic and lithologic evidence into five formations. The lowest (oldest) comprises the upper part of the Weber quartzite, which yields a Pennsylvanian (upper Carboniferous) fauna. Overlying this quartzite is the Park City formation of limestone and sandstone, the former bearing Pennsylvanian fossils. Next above is the unfossiliferous Woodside shale, which is succeeded by the Thaynes formation. The limestones in this formation yield a new fauna resembling both Carboniferous and Permian, considered of "Permian age." The highest beds in the district are the unfossiliferous shales constituting the lower part of the formation which passes upward a few miles northwest of this area into the Triassic sandstone, and thence into the Jurassic limestone.

WEBER QUARTZITE

Name.—About 30 miles due north from Park City and 1 or 2 miles west from Croydon station, the great gray quartzite of the Wasatch section forms both walls of Weber Canyon. "It is from the characteristic occurrence of this remarkable bed of quartzite that the name 'Weber quartzite' has been given to the body" by the geologists of the Fortieth Parallel Survey.[1]

Critical paleontologic and stratigraphic studies lead to the conclusion that the great quartzite of the Park City district is the stratigraphic equivalent of the Weber quartzite in Weber Canyon. Accordingly the name "Weber" will be extended to apply to this formation in the Park City district. Locally it has been known, after the famous mine which lies in it, as the "Ontario" quartzite.

[1] Clarence King, *Geological Exploration of the Fortieth Parallel Survey*, Vol. I, p. 161.



Character Fossil bearing horizons	Thickness	Formation	
Red shales—locally sandy—with interbedded coarse gray sandstones. Carries in lower portion *Aviculipecten Weberensis, A. curticardinalis, A. parvulus, Myalina permiana.* No economic importance.	1.500+ feet	Ankareh Shale	Permian
Calcareous with sandstones and shales, "Mid-red" shale separates more calcareous upper from more arenaceous lower portion. Carries large fauna, with many new fossil species chiefly pelecypods including *Pentacrinus* sp.. *Myalina permiana, M. aviculoides, Aviculipecten curticardinalis, A. Weberensis, A. parvulus, A. occidaneus*, Lingulas, Spirifers, Dentalia. Forms country rock for replacement ore bodies and lodes.	1,190 feet	Thaynes Limestone	Permian
Red shale—thinly bedded—fine grained. Bears ripple marks, mud cracks, raindrop imprints. No direct economic importance.	1,180 feet	Woodside Shale	Permian
			Carboniferous
Calcareous with interbedded quartzite, sandstones and some shale. Carries Lingulidiscina sp., Productus cora, Productus sp., Plagioglypta canua, Euphemus subpapillosus, Bellerophon, sp. Forms country rock, for principal bonanza replacement ore bodies.	590 feet	Park City Limestone	Pennsylvanian
Gray quartzite, massively bedded, homogeneous, dense. Carries, in Weber Canyon, *Lingula* sp., *Productus subhorridus, Schizodus* sp., *Plagioglypta canua, Euphemus subpapillosus.* Forms wall or walls of lead-silver lodes.	1.350+ feet	Weber Quartzite	Pennsylvanian

umnar section of portion of Carboniferous, Big Cottonwood Canyon, Wasatch Range, Utah

Character.—That part of this formation which outcrops in this region is made up of gray quartzite, with comparatively insignificant exceptions of cherty patches and intercalated limestone. This, the upper portion, is characterized by its general massiveness, both in bedding, which is rarely less than 4 and frequently 8 to 15 feet in thickness, and in absence of parting planes. On fresh fracture it is light brownish-gray in color, and it weathers to a glistening polished surface of a lighter whitish shade. The normal quartzite is fine, even-grained, and dense. The exceedingly brittle nature of the rock causes it to chip into sharply angular irregular fragments, or, when ground up in a fracture zone, to appear as a glistening white, sugary portion, inclosing less finely comminuted quartzite. The cleanness of the rock has been demonstrated by repeated chemical analyses, which show a very high percentage of silica. Thus analysis of a specimen of this quartzite from Big Cottonwood Canyon shows 95.80 per cent. of silica.

These lithologic characteristics are maintained with remarkable uniformity throughout the formation. Exceptions noted within this district are so rare as to be insignificant.

Topographically this quartzite stands up as knobs or ledgy massive blocks and as prominent broad spurs falling off by precipitous slopes.

That part of this great formation which is not present in this area, embracing the middle and basal portions, outcrops in prominent cliffs just south of this district. Excepting a few thin limestone beds near its top, the middle portion is massive quartzite, and in the lower part the intercalated limestone members increase in number and thickness. In Big Cottonwood Canyon the massive, dense character of the quartzite is preserved, and a few limestones are intercalated. A thin, crinoidal sandstone occurs about 130 feet from the top; a thin, pitted, cavernous, grayish-white quartzite, 460 feet below that; and a thinly banded, calcareous quartzite, 430 feet farther down. In Weber Canyon this great formation is most characteristically exposed as a massive, dense, homogeneous quartzite. The insignificant exceptions are a curiously pitted and marked horizon of quartzite just below the top and a few thin limestones in the basal portion.

Distribution and thickness.—The main area of this formation

exposed in this district is an oblong tract which extends south from Park City about 3 miles, with an average width of a mile. From Bald Mountain an irregular, much broken arm extends eastward between two great faulted zones, and to the south and southwest about the eastern end of Bonanza Flat are isolated horses in intrusives. This quartzite forms the outcrops on the slopes which inclose Park City on all sides. It is particularly well exposed on the salient bluffs west of the city, and is deeply incised by each of the canyons which lead south up to the mines. Characteristic outcrops have been revealed in Woodside Gulch by cutting the King Road between the Alice and Woodside properties; in Empire Canyon in the vicinity of the adits to the Daly Judge and to the Alliance tunnels, and in upper Ontario Canyon.

The thickness of the portion of this formation which appears in this district cannot be determined precisely, because nowhere within the area was a continuous exposure observed. The Ontario No. 3 shaft and workings cut "Ontario" quartzite, dipping about 20 degrees, to a depth of 1,620 feet, or a thickness of approximately 1,500 feet. The collar of the shaft lies on the side of a canyon which has been cut deep into the formation below its upper contact. This contact is exposed elsewhere to the north and northwest, but the thickness of quartzite which has been removed by denudation down to the stratigraphic horizon in which the collar of the shaft is located is uncertain, except that it is several hundred feet. The thickness of Weber quartzite exposed within the district may thus be regarded as approximately 2,000 feet. The minimum thickness of the underlying portion would be 1,500 feet. The accurate determination must await the working-out of structure and measurement of any possible great faults. Pending that, it may be tentatively considered as 3,500 feet. The thickness of the part exposed on the north side of Big Cottonwood Canyon was 1,340 feet. King and the geologists of the Fortieth Parallel estimated the thickness exposed in Weber Canyon to be 6,000 feet.

Age and stratigraphic relations.—The geologic age of the Weber quartzite was regarded by the early geological workers in this region as "Upper Carboniferous." They did not find fossils in the quartzite itself, but based this conclusion on the stratigraphic relation of this formation to fossiliferous limestones above and below.

During the present investigation paleontologic evidence was obtained from the quartzite itself, from limestone intercalated in its lower portion, and from overlying limestone formations, which definitely proves the age of the Weber quartzite to be "upper Carboniferous". During the season of 1903 Dr. T. W. Stanton discovered fossils in the quartzite in Weber Canyon. They occurred about 2 miles west of Croydon Station, and at 1,800 to 2,000 feet below the top of the Weber quartzite formation.

These fossils prove this quartzite to be of Pennsylvanian (upper Carboniferous) age. No fossils have been found, in the quartzite within or adjacent to the Park City district. Definite faunas were obtained, however, from limestones intercalated in the quartzite on the north side of Snake Creek which underlies the part which outcrops in the Park City area. These collections (101–7), like those from the formation in Weber Canyon, show faunas of Pennsylvanian (upper Carboniferous) age. Further, faunas from overlying limestone formations in both the Park City and Weber Canyon areas are Pennsylvanian. Accordingly the occurrence of Pennsylvanian faunas in the base of this formation and overlying limestone demonstrates that the age of the Weber quartzite is Pennsylvanian. The transition in Weber Canyon from the underlying great Wasatch limestone formation to the Weber quartzite is by gradually increasing siliceous contents through varicolored sandstones, which give way to alternating limestones and quartzites, and finally to quartzite with intercalated limestone. In Snake Creek the passage upward and northward into the Weber quartzite is by a corresponding succession of limestones intercalated in quartzite.

The passage from this great quartzite into the overlying formation had been subjected to considerable study without definite results. Accordingly in the present investigation special attention was given to this question. It had been reported by one geologist that a marked unconformity existed between this quartzite and the overlying limestone. During the present survey no unconformity was found. On the contrary, excellent exposures showed on careful inspection apparently complete conformity. The lithologic character of the sediments also indicated that a full record is here shown of a gradual normal transition. Exposures in Woodside Canyon show a succes-

sion of calcareous sandstones, normal sandstones, and arenaceous quartzites immediately above characteristic massive Ontario quartzite —apparently a normal transition. In Big Cottonwood Canyon, a few miles to the west of this area, the quartzite gives way upward to a sequence of sandy beds. In Weber Canyon the precise contact was not sufficiently exposed to demonstrate conformability, but the limit and extent observed gave no evidence of unconformity. Immediately overlying normal Weber quartzite is a coffee-colored and white sandstone, variably coarse and fine, about 150 feet thick, succeeded by the regular calcareous succession.

These accordant features, lack of reliable evidence of unconformity, and a lithologic succession tending to show conformity between these formations, are further supported by paleontologic evidence. In the Park City District the base of the overlying limestone formation carries a distinctive fauna. Members of this same fauna, as indentified by Dr. Girty, occur in Weber Canyon in the equivalent limestone at a corresponding distance above the quartzite (about 250 to 300 feet), and also about 1,800 to 2,000 feet below in Weber quartzite. This fact in itself seems to show conclusively that no break in the paleontologic succession took place, and thus that there was no break in the sedimentation, or, in other words, that the Weber quartzite and the overlying limestone formation are conformable.

PARK CITY FORMATION

Name.—The Park City formation is named after the district, in recognition of the fact that it is the formation which has yielded the bonanzas that during the last decade have made the district famous.

Character.—This formation is made up in large part of calcareous members, but it also embraces several sandstones and quartzites. In general, it comprises a thick limestone in its lower part, several minor limestones in its upper part, and a number of thin calcareous beds toward the base, with intercalated quartzites and sandstones. Along the King road the lower portion of the formation is seen to be made up of normal gray limestones, cherty limestones, brown calcareous and shaly sandstone, red, brown, and olive shales. The lower half of the formation is there seen to include two important limestone members and three minor quartzites. Overlying these,

and forming the top of Treasure Hill, are various types of siliceous beds, sandstones, quartzites, etc.

The exposure in the type section a few miles to the west in Big Cottonwood Canyon presents the best section observed.

Type Section, Big Cottonwood Canyon

Thickness in Feet	*Description*
19	Grayish-white limestone, with fine gray and white cherts increasing toward bottom.
19	Shale and fine buff sandstone.
7	Dark-gray limestone, thin chert, red shale, and porous loose member at base.
11	Sandy shale.
21	Yellowish-gray quartzitic sandstone, changing into cherty white limestone below.
52	Gray and white banded chert, with few white sandstone intercalations.
8	Fine calcareous sandstone, with lentils of chert and brecciated fragments of sandstone.
104	Float of buff sandstone and shale, becoming more shaly and calcareous at base.
18	Siliceous arkose, comprising mainly rounded quartz grains and feldspars cemented with ferruginous material.
20	Compact grayish quartzite.
8	White, compact, sugary sandstone, fossiliferous at base.
30	Fine gray and pink, massive quartzite, with brown sandstone and gray-white chert bands near base.
27	Light-gray limestone, weathering whitish gray with an imbricated pattern; fine gray limestone near base; carries good faunas at two horizons in particular, 20 and 55 feet above the base respectively.
24	Gray calcareous sandstone.
9	Fine gray limestone.
36	Float showing bits of grayish and brown calcareous sandstone.
22	Sandy limestone, more calcareous at base, with cavernous weathered surface.
31	Float, upper sandy beds at top of Weber quartzite.

Distribution.—The Park City formation extends around the center of the district in the general form of a U (with base pointing north). Its irregular and interrupted outcrop stretches from Bonanza Flat northward across the prominent eastern spur, passing the Daly West, Daly, and Silver King mines, thence northerly to a point opposite

Park City, where it swings northeast and eastward around to the north of the city, whence, continuing the curve, it reappears with a southerly strike near the base of the eastern slopes of the range. The continuity of this general course has been much interrupted by intrusives, extrusives, and faulting. The most characteristic, and also the most extensive, exposures are those lying west and east of Park City, forming respectively Treasure Hill and Twin Knobs.

This formation characteristically forms domar knobs and spurs of moderately steep slope intermediate in degree between the resistant quartzite below and the non-resistant shale above. No good natural exposures of the entire formation are known in this area. The absence of cliff-making members, the presence of weaker members, and the thick growth of aspen and brush which characterize this formation, all contribute to cover its surface, to render it inaccessible, and to prevent careful examination and measurement of its members.

Thickness.—The exposures in this area do not afford a basis for a close estimate of the thickness of the Park City formation. Crosscuts in the Silver King and Daly West mines should, under normal conditions, yield the desired data, but strike-faulting in both properties has so complexly duplicated the succession as to render measurement of its thickness little more than approximation. The total thickness indicated by the Treasure Hill body is approximately 700 feet. The best and the only reliable section observed is the type section in Big Cottonwood Canyon, described above. The thickness of this formation at that locality measured 590 feet.

Age and stratigraphic relations.—The age of the Park City formation is proved, by several faunas collected from calcareous members in the district in Big Cottonwood Canyon and in Weber Canyon, to be Pennsylvanian (upper Carboniferous). Two of the type fossils are particularly indicative: the Bellerophon, as seen in the lower portion of the formation along the King road, in Woodside Gulch, and the Orbiculoidea, of common occurrence in the gray shaly limestones, the lower part of the formation throughout the district. The identification of these faunas in the Cottonwood and Weber Canyon regions makes possible the correlation of this formation with its equivalents to the west and north. The association of *Bellerophon* sp., *Productus cora*, and *Orbiculoidea* sp., and the stratigraphic position of these faunas

leads Dr. Girty to suggest the correlation of this formation with the Bellerophon limestone in the Uintas. With regard to the position of the ore-bearing limestones of this formation in comparison with that of others in the Utah mining camps, they appear to be somewhat higher than the Highland Boy, Commercial, and Jordan limestones at Bingham (upper portion of the Weber quartzite); higher than the Great Blue limestone at Mercur (the Wasatch, Mississippian, or lower Carboniferous); higher than the Eureka and Godiva limestones at Tintic (Mississippian); and higher than the great limestone of Emma Hill at Alta in middle Cottonwood Canyon (Mississippian or lower Carboniferous). Thus the Park City formation is much younger than any of the limestones in Utah which have been found to bear ore bodies, except those at Bingham, and it is believed to be next younger than the Bingham formation.

No unconformity was observed with either the underlying Ontario quartzite or the overlying shale, or between members within the formation. Accordingly it would seem that sedimentation proceeded unbroken from Mississippian time on through that period of the Pennsylvanian represented by the Park City formation.

WOODSIDE SHALE

Name.—The Woodside shale is named after Woodside Gulch, as the best exposed section of these sediments in the district is at the head of this gulch, on the slope which overlooks the Silver King plant from the west.

Character.—This great formation is a lithologic unit, being composed from bottom to top, without significant exception, of fine-grained, dark-red shale. A shaly parting sometimes gives way to very thin laminations, but the general homogeneous lithologic character is maintained with wonderful uniformity. In rare exceptions a slight increase in coarseness of texture produces a fine grained sandstone, or variations in color result in buff, brown, and greenish-gray shales; but such variations are extremely limited in number and extent.

The characteristic topography which has developed on such a lithologically homogeneous formation is a full, even, uninterrupted slope. This is commonly densely overgrown with rank grasses, shrubs and aspen.

The formation has no direct economic importance, as it affords neither ore bodies nor building stone, nor other economic products. Indirectly, however, its tendency to take off surface drainage and its enormous capacity for water render it an important factor in mining, especially in sinking deep shafts or in running long tunnels.

Distribution and thickness.—The Woodside shale appears in this district in three principal areas. In a highly metamorphosed condition as spotted dark-red and green argillite it occurs on the north face of Jupiter Peak and northward along the east side of Pioneer Ridge, and also as an argillite in the gap next west of Lucky Bill gap and on the north side of the Quincy spur. In its normal development it appears northwest of the Daly West shaft from the Morgan shaft to the Diamond-Nimrod shaft and along the west side of Empire Canyon, and especially characteristic in the slope above and to the west of the Silver King mine. To the east of Park City it reappears striking southerly on the eastern slope of the range.

The thickness of this shale varies considerably. In the type section of Big Cottonwood, which was studied and measured with unusual care, this formation was found to be 1,180 feet thick. In the Park City district the best opportunity for its determination was afforded by the sinking of the deep shaft by the Silver King Consolidated Company, although even this is not entirely free from possibly inaccurate estimate owing to faulting. This shaft is located on the northeast side of Crescent Ridge just over the divide northwestward from the Silver King property. It passed through this red-shale formation for a distance of 800 feet, which, reckoning the average dip as 30°, affords a thickness of 700 feet.

Age and stratigraphic relations.—No fossils were observed in this shale, neither was any stratigraphic evidence found which would directly connect this formation in age with either of the inclosing fossiliferous formations. Lithologically, however, this shale finds its equivalent in one important member and several thin ones in the next overlying formation and in the great thickness of red shale of the Ankareh formation. These lithologic resemblances show that the conditions under which this formation was deposited were those which prevailed during the deposition of the succeeding rather than that of the preceding formation. Accordingly the Woodside shale

will be grouped with the overlying fossiliferous limestone as of Permian age.

THAYNES FORMATION

Name.—This formation is named Thaynes after a canyon whose deep and extended incision affords the best exposures of this formation within the district.

Character.—This is essentially a calcareous formation. It comprises two parts separated by a red-shale member, each made up of limestone, calcareous sandstone, normal sandstone, and shale. Most of the true limestones are in the upper part, and the sandstones predominate in the lower part, though each type is found throughout. A very characteristic lithologic type occurring at many horizons in the formation is a dense, homogeneous, blue-gray, calcareous sandstone, which appears superficially to be a limestone, but on exposure to the weather loses its low calcareous content and becomes a medium fine-grained, brown sandstone. These are among the richest fossiliferous members of the formations, as is shown below. These members, the abundant and characteristic faunas, and the red-shale member—the "mid-red" shale—serve to mark this formation and to enable one readily to distinguished it from the Park City formation. Topographically, the outcrop forms abrupt cliffs, and the dip slopes and basset edges, broad flat slopes. Its surface is brushy and ledgy. A number of partial sections were measured and studied with great care for purposes of correlation, identification, and structural proofs. No complete sections or exposures which were not complexly faulted, intruded, or metamorphosed, which would serve for a standard section, were found within the district. The nearest point where suitable exposures could be found was about 3 miles west, in the north side of Big Cottonwood Canyon, where in several parallel spurs this formation occurs in excellent unbroken exposures. The composition of the formation in that section, including lithology, thickness, and fossil characteristics, is briefly stated below:

SECTION OF THAYNES FORMATION (PERMIAN) IN BIG COTTONWOOD CANYON

Lithology

Thickness in Feet	
1	Sandstone, massive, even, fine-grained, basal member, Argenta formation.
1	Limestone, blue, locally sandy, fossiliferous.

Thickness in feet	
12	Shale, fine, gray-green.
½	Limestone, blue-gray, cavernous, fossiliferous.
2½	Limestone transition from shale through sandstone, fossiliferous.
14	Sandstone, gray-brown, with calcareous shale intercalations, fossiliferous.
5	Shale, maroon, fine-banded.
½	Limestone, gray, impure, semicrystalline, fossiliferous.
24	Limestone, light gray-blue, massive, sandy, fossiliferous.
16	Shale, gray-brown.
5	Limestone, impure, gray, massive, fossiliferous.
4	Shale, gray to buff.
14	Sandstone, massive, gray-brown, vertical sheeting, fossiliferous.
42	Shale and sandstone, green to brown, calcareous intercalations.
4	Sandstone, gray, finely laminated, chert lenses.
8	Shales.
20	Limestone, fine, blue, with intercalated ripple-marked sandstones, lenticular gray cherts, and biotitic bed, bearing fossils.
15	Shale, olive.
4	Sandstone, olive-gray, massive, weathers rusty, trails, fucoids, and imprints.
5	Limestone, bluish, matrix inclosing "tangle" stringers of ferruginous sandstone.
4	Limestone, impure, blue, very fossiliferous.
19	Shale, olive, fine-grained.
7	Limestone, sandy and shaly.
8	Limestone, blue to gray, spheroidal weathering, fossiliferous.
14	Débris, lime with intercalated shale.
14	Limestone, dark blue, locally shaly, weathers rough, several highly fossiliferous horizons.
10	Shale, brown, inclosing sandy bed.
5¾	Limestone, gray-blue, gray chert lenses, fossiliferous.
4	Shale, brown with green tinge.
6	Limestone, coarse shells, gray chert band.
14	Limestone, dark blue, sandy, massive.
35	Limestone, deep blue, weathers rusty, fossiliferous.
11	Sandstone, calcareous, rusty, breaks in slabs.
10	Limestone.
66	Sandstone, gray-black, shaly, bands black slaty shale, fossiliferous.
168	Sandstone, calcareous, finely laminated, highly fossiliferous.
20	Shale, maroon.
30	Float, varicolored shale.
64	Shale, green, buff, olive, maroon, yellow.
34	Sandstone, gray, calcareous, intercalated shales.
5	Limestone, gray, intercalated, calcareous, gray sandstone.
14	Sandstone, greenish-brown, intercalated shales.

Thickness in feet	
4	Limestone, gray-blue, fossiliferous.
17	Shale, olive, with three fossiliferous argillaceous limestones.
5	Limestone.
370	Limestone, blue; shale, olive-brown; sandstone, calcareous; alternating series, varying much in color and texture, fossiliferous.

Talus, containing shale regarded as top of Woodside formation.

Distribution and thickness.—The Thaynes formation is one of the two most extensively exposed formations in this district. On the western flank of the Park City anticline it forms both of the inclosing walls of Thaynes Canyon from head to mouth, all the middle and headward portions of White Pine Canyon, and thence strikes southwest into Big Cottonwood Canyon. It is again seen in the main fault zone of the district overlying the great mines. Thus it forms the prominent ledges west of the upper portion of Empire Canyon, just opposite the Daly Mine, the spur extending from the Daly West mine to Morgan Knob, and the cliffs which overlook the Daly Judge amphitheater. On the eastern flank of the anticline the cropping of this formation is exposed about the heads of Heber, McCune, and Pocatello gulches, and at the extreme southeast crops in a triangular area just north of Cottonwood Canyon.

The best measure of the thickness of this formation was obtained in Big Cottonwood Canyon, where, as shown above, the upper part amounts to 630 feet, the "mid-red" shale to 115 feet, and the lower part to 445 feet, the whole formation thus aggregating 1,190 feet. Within the Park City area proper no exposure was found suitable for measurement, so complex and universal was the deformation in this region. The difference in thickness of exposures of this formation on the eastern and western sides of the district may be apparent rather than actual, as on the Heber road near the top of the eastern exposure red-shale crops which is probably the "mid-red" shale, and the same is true in the Cottonwood exposure. It would thus appear that the eastern exposures embrace a portion of the formation only—that is, the part lying below the "mid-red" shale, the upper portion being either truncated by intrusives or buried by extrusives.

Age and stratigraphic relations.—Excellent fossil evidence indicates that the geologic age of the Thaynes formation is probably Permian.

Dr. Girty, who has examined the faunas collected from it and prepared the list of species given below, states that

"the fauna and horizon are those which in the Fortieth Parallel Survey Reports are called Permo-Carboniferous in the Wasatch and Uinta Mountains. The fauna consists almost exclusively of pelecypods, chiefly pectinoids, a few of which are described in the reports above referred to. With these exceptions the fauna was entirely new to me. . . . . It now seems probable that the fauna will be correlated with the Permian of the Grand Canyon section, and will prove to be in fact Paleozoic."[1]

The limestones and the peculiar calcareous sandstones are rich in organic remains. In their characteristic and distinctive fauna three forms are almost universally present, *Myalina*, *aviculipecten*, and *lingula*, while Spirifers and Dentalia are usually present in faunas from limestones. The first three forms are found throughout the Thaynes formation, including the highest and lowest members, and are indicative of this formation. *Pentacrinus*, which also serves as a valuable index, is limited to the part lying above the "mid-red" shale. The following species in the list submitted have been identified by Dr. Girty:

PARTIAL LIST OF PERMIAN FOSSILS IDENTIFIED IN PARK CITY DISTRICT

Pentacrinus sp.	*Aviculipecten curticardinalis*
Myalina permiana	*Aviculipecten Weberensis*
Myalina aviculoides	*Aviculipecten parvulus*
Aviculipecten occidaneus	

In addition to these recognized forms, Dr. Girty states that the collections from this formation in the Park City District include fully thirty new species, and that nearly as many more have been found outside the district.

In its stratigraphic relations this formation is intimately related to the two inclosing shale formations, in that during its deposition the same conditions frequently prevailed as during their deposition. No great unconformity either above or below was noted, though a slight unconformity by erosion was observed at one horizon within this formation, and others doubtless exist.

The persistence of certain members of the Thaynes formation is noteworthy. Thus the "mid-red" shale, with a thickness of only

[1] Extract from report on collections submitted by the writer for identification by Dr. Girty, Paleontologist, U. S. Geological Survey, dated August 11, 1903.

115 feet in the Park City area, is found 3 miles to the west in the Big Cottonwood region and 40 miles to the north in Weber Canyon. Still more noteworthy is the occurrence of thin limestones at equivalent stratigraphic positions in the formation and bearing identical faunas in this district, and again in the Big Cottonwood section 2 to 3 miles to the west. Not sufficient work in following special members was done to warrant the affirmation that this persistence or equivalency is actual stratigraphic continuity, though in the case of the thicker formations this is doubtless true, and it is probably true of some of the thinner limestones. This striking continuity probably indicates that the conditions under which these members were formed were brought about over extensive areas by wide-spread land movements of equal intensity throughout the region.

ANKAREH FORMATION

Name.—The name for this formation is taken from the ridge on which it attains its fullest and most characteristic development within the district. The ridge has been named by the writer for the purpose of rendering descriptions shorter and more definite. One of the most striking characteristics of this ridge is the red color imparted by the shales, and as *ankareh* is the word for "red" in the dialect of the Uinta Utes, the local Indian tribe, the adoption of the word *Ankareh* as the name of this ridge seems most fitting. The extension of the use of this term from the ridge to the formation is no less appropriate, as this formation constitutes the base of the main red shale and sandstone formation in the Wasatch, whose striking red color is most characteristically displayed on prominent spurs immediately west of Park City.

Character.—As a whole, this formation is composed of siliceous détrital deposits. They are chiefly red shales, which frequently become sandy through considerable thicknesses. It also includes a number of well-marked beds of rather coarse, whitish-gray sandstone, which range from 20 to 55 feet in thickness. A few fossiliferous, grayish-blue limestones are also intercalated, but these are exceptional and only a few feet thick. The division between this and the underlying formation is made on lithologic grounds, calcareous members characterizing the Thaynes formation and siliceous the Ankareh

formation. For the basal member the coarse, massive sandstone is taken which lies at the base of the red shale as a whole, and immediately overlies a thin limestone. Only a portion of this formation occurs within this district, the highest part being marked by a prominent massive, white sandstone member.

The non-resistant character of the beds of this formation as a whole results in the topographic development along its outcrop of even full slopes, which are broken only by benches on the sandy members. These slopes are usually thickly covered with aspen, rank grasses and brush. They are dry, rarely forming water sources. No economic values, either in ore or in stone, have yet been found to occur in its members.

Distribution and thickness.—The formation outcrops in only two areas within the district. The principal one is an N-shaped zone in the extreme northwestern corner of the area; thence it strikes westerly, and is plainly visible in characteristic topographic and lithologic development on each of the succeeding ridges to the west of Park City which head at Big Cottonwood Canyon. The second area, which has never been recognized as such hitherto, is on Pioneer Ridge, between Crescent Ridge and Jupiter Hill, where red shale of this formation forms the spur between the Kearns-Keith or Sampson amphitheater and the Jupiter amphitheater immediately south.

The best exposure for the measurement of the thickness of that portion of the formation which crops in this district is at the west side of Thaynes, toward its mouth. This was carefully studied and measured, but, owing to frequent interruption by vegetation and débris, it is incomplete, and, owing to the probability of deformation by faulting, any estimate of the thickness would be of little value. In the Big Cottonwood standard section the thickness of the portion which crops in the Park City District was found to be 1,300 feet.

Age and stratigraphic relations.—The age of the Ankareh formation, so far as indicated by meagre paleontological evidence, is Permian. The fossil evidence on which this determination is based comprises three lots from the standard Big Cottonwood Section and scattering collections from within the Park City District. The lowest two lots, one from coarse sandstone, the other from a thin limestone, both within 200 feet of the Thaynes formation, belong with the fauna

of the underlying limestone, and like it are Permian. This definitely fixes the lower portion of the Ankareh formation as Permian, but the division between this known portion and the overlying shales and sandstones which have been considered Triassic, remains undetermined. In the standard section just below the main sandstone member, and in the Thaynes section in this sandstone succession, petrified wood and bark were found; but these hardly marked the age of the inclosing beds. For the purpose of this report the portion of this formation which lies within this district may be considered as Permian. The delimitation of the upper part may best be left to future workers in adjacent areas where the entire section is exposed.

Stratigraphically the lower part of this formation is shown by the character of the included faunas to belong with the Permian. Doubtless deposition took place without interruption between these formations. The transition upward into sandstones, which are well bedded and also coarsely crossbedded, points to probable depression from shore conditions to slightly deeper water and strong currents.

TRIASSIC

Within this district no sediments have been found which carry Triassic fossils. To the north and northwest, however, the Park City formations pass upward through several hundred feet of red shale into brown, red, pink, and white sandstones. These are frequently massive and heavily bedded, in striking occurrences are coarsely crossbedded, and toward the top are quartzitic. Disregarding possible faulting, they aggregate about 1,550 feet in thickness. The age of these sandstones has always been regarded as Triassic, as they overlie Permian and underlie Jurassic.

JURASSIC

Overlying these sandstones is a succession of fine-grained gray limestones several hundred feet in thickness, which yielded sufficient organic remains to prove them of Jurassic age. These roughly measured 400 feet in thickness, and were overlain by concealed, partly calcareous beds about 500 feet in thickness.

The following forms in these collections have been identified by Dr. T. W. Stanton:

Camptonectes pertenuistriatus Hall & Whitfield.
Cucullaea haguei Meek ?
Astarte sp.
Pleuromya subcompressa Meek.
Cerithium? sp.
Nerinea sp.
Gryphaea calceola var. *nebrascensis* M. & H.
Pinna kingi Meek.
Cyprina? sp.
Pentacrinus sp
Ostrea sp.
Lima (*Plagiostoma*) *occidentalis* Hall & Whitfield.
Gervillia sp.

GENERAL STRUCTURE

In the course of mapping the above-described geologic formations in this district, and of reconnaissance work in adjoining areas, several structural features were discovered which bear significantly upon the location and deformation of the ore-bearing formations. Some time must necessarily elapse before the complete report giving these results can appear. Accordingly, in response to several urgent requests from operators for information, this opportunity is taken to present without further delay a general statement of some of the more important structural features.

The general anticlinal structure of the Paleozoic and Mesozoic beds which characterize the Wasatch as a whole is interrupted in this central portion by a transverse (east-west) anticline or dome. Sediments ranging from Cambrian to Tertiary here dip northerly and southerly quaquaversally from a series of laccolithic masses. These include, from west to east, the porphyritic granite of Lone Peak and Little Cottonwood Canyon, the granodiorite at the head of Little Cottonwood Canyon in the vicinity of Alta, the coarse and fine-grained dioritic masses at the heads of Big and Little Cottonwood Canyons, and the northeast extensions in the form of dikes. These several masses constitute a mammoth composite laccolith. It is noteworthy that these intrusions have taken place along a zone coinciding in location and course with the extension of the Uinta axis across the Wasatch. This fact, together with the influence of these masses in doming the structure athwart the general course of the Wasatch, naturally raises a query as to a similar influence in the formation of the Uintas. This transverse Wasatch dome and the Uinta dome are separated topographically, though not structurally, by a north-south

trough. Into this, and thus blanketing the surface connection of these structures, extensive and thick masses of andesite have flowed.

That portion of this region known as the Park City District is traversed diagonally by this axis. The sediments in this area have been cut, deformed, and altered by a series of intrusives, and andesite flows cover the sediments at the northeast. These sediments rim around the intrusives and dip off from their flanks. The area thus embraces the northeast end of the great composite laccolith of the middle Wasatch.

The broad structure of the formations within the Park City District proper is that of an anticline pitching northerly. The general strike follows the course of a U, the base of the letter being at the north. At the center, along the main axis which passes north-northeast just east of Park City, occurs an extensive area of Weber quartzite, from which the overlying younger formations dip—in general to the west side on the west and to the east on the east. Immediately north of Park City these strikes converge and unite to form the nose of the pitching fold.

This structure, however, is true only in a general sense, as it is greatly modified by minor folding and extensive faulting. Athwart this anticline, in a general east-west course, extends a series of intrusive masses. These include the diorite stock of Clayton Peak at the extreme southwest, east of this the stocks and dikes of andesite porphyry which extend eastward diagonally across this area and upward through all sedimentary formations from the Weber to the Thaynes, and next beyond to the east extensive thick flows of andesite. These are the highest members of the chain of intrusives which lie athwart the course of the range at this point. They occupy the normal position of sediments, and thus interrupt the general anticlinal structure above described to only a minor degree by local folding.

Three great systems of fracturing and faulting further break the broad structure, trending north-south, northeast-southwest, and northwest-southeast (east-west), respectively.

One of these fracture systems cuts across the nose of the anticline on its northeast side as a north-south line of dislocation, which is marked by the eastern inclosing wall of Deer Valley Meadow and Frog Valley. Along this fault the displacement has been such that

the eastern side lies farther south than the western. In the same deformational sense the western member, especially that area of Weber quartzite lying east of Park City and that forming Bald Eagle Mountain, has moved eastward up this same fault plane, overriding geologically higher formations. As a result of this extensive overthrust faulting, two formations, aggregating 2,000 feet in thickness, have been overridden until the Weber outcrops against the Thaynes formation. The economic importance of this discovery lies in the fact that the principal ore-bearing limestone of the district which had been believed hitherto to strike north from Park City and to disappear beneath the extrusives, in reality occurs immediately east of the settlement in an easily accessible locality.

The principal zone of fissuring in this region trends across the central portion of the district in a northeast-southwest direction and dips steeply toward the northwest. It embraces the lodes which have afforded the valuable output from the Ontario, Daly, Daly West, and Daly Judge properties. The faulting on the main fissure of the system in its eastern extent, the Ontario, as measured in the vicinity of Ontario shaft No. 3, was relatively a downward movement of the north or hanging wall side, aggregating 330 feet. Correspondingly great dislocation occurred on the most important member of this system in its western part, the Daly-Daly West fissure, also on other members; and in certain instances a relative downward movement of the *south* or hanging wall side of south-dipping fissures is clearly shown.

North of this zone members of the northwest-southeast system appear in a series known after its principal member, the Massachusetts fault. This may be best seen trending west-northwest and standing about vertical in the Daly Judge tunnel and at the Massachusetts shaft. Its structural importance lies in the fact that the north side has been moved along it relatively westward about 2,500 feet. Its economic importance arises from the fact that its recognition and solution answers the hitherto standing query as to the relation of the ore-bearing limestones of the Silver King and Daly West properties, respectively; namely, they are portions of the same formation—the Park City limestone.

A similar result of these east-west faults is shown on the west side

of Empire Canyon, opposite Daly shaft No. 2. The limestone cliffs forming that wall of the canyon terminate abruptly on the north, and the same beds (Thaynes limestone) reappear 5,000 feet to the west in Crescent Ridge, on the north side of a strongly defined east-west fault.

A significant fault structure has also been brought out in the course of this work to the east of the Ontario fracture zone, on the extreme eastern slope of the range. A block (or wedge) averaging 2 miles in width north and south, and made up of the regular sedimentary succession, including the Weber to Thaynes formations and intruded andesite porphyries, has moved bodily to the east at least 2 miles. Its northern limit is a strong east-west fault, followed by McHenry Canyon. Its southern wall is a companion fault which crosses Cottonwood Canyon near its mouth about a mile southeast of the Valeo Mine. The economic significance of this discovery is that the desirable ore-bearing limestones should not be sought in their normal strike and position, and that within the extent of this block they lie at least 2 miles beyond to the east at an unknown depth beneath thick andesite extrusives. The scientific bearing of this structure, however, is of deeper interest, in view of the present eager search for evidence on the manner of intrusion, especially as to the disposition of the rock which previous to intrusion occupied the space subsequently taken by the igneous mass. The general aspects of this occurrence are most suggestive.

From the foregoing statements regarding intrusives and structure, it is to be noted that a series of intrusives lie in a narrow east-west belt extending across the range; that these appear on other distinct evidence to have invaded this area from the west, breaking upward and eastward; that the intrusives in this area are thus the highest and easternmost members; that in the path and ahead of this chain of intruded igneous masses occurred the maximum deformation and dislocation; that slightly to one side on the north sediments were broken and driven eastward over geologically higher members; and that directly ahead of the invading wedge of intrusives the country gave way and moved eastward at least 2 miles.